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STABILITY OF ASPHALT CEMENT CONCRETE PRODUCED FROM WASTE PLASTICS AS REPLACEMENT FOR AGGREGATE

[1]D.B. Eme, [2]T.C Nwofor, [3]E.S. Umukoro

[1,2,3]Department of Civil Engineering, University of Port Harcourt, Nigeria

ABSTRACT

The use of plastic bags subjected to pyrolysis at 120^0C to produce plastic pellet as partial replacement for coarse aggregate in asphalt cement concrete is investigated in this paper. Optimum binder content was determined by Marshall test procedure and used for plastic pellet content of 0%, 2%, 4%, 6%, 8%, 10% and 12% by weight of coarse aggregate for asphalt concrete production. Three specimens for each percentage plastic pellet content is prepared with result based on Marshall design criteria for medium traffic. Results of the asphalt cement concrete showed that 2 to 4 percent of plastic pellet content satisfied Marshal's requirements, hence the use of plastic pellet as partial replacement for coarse aggregate was recommended within this limit.

Keywords: Asphalt Cement Concrete, Plastic Pellets, Pyrolysis, Stability, Flow

I. INTRODUCTION

The menace of pure water sachet is common to all the markets, commercial centers and most streets in Nigeria. The problem is essentially spawned by the growing business of packaging small quantities of water in sealed nylon for sale to the public, which began some years ago. The problem is further compounded by the improper waste disposal culture of Nigerians as many simply discard the sachets carelessly after consuming the water. As a result, most rural and urban solid waste contains significant quantities of non-compositing plastic waste.

Furthermore, the Federal Government's positive stride in the petrochemical sector has escalated the use of plastic material and subsequent generation of large quantities of plastic waste. Incineration which seems to be better waste disposal method fails in handling plastic waste as toxic gas, hydrochloric acid and chlorine gas are emitted in the process. A waste plastic disposal method which eliminates contaminated combustion residues and maximizes solid waste volume reduction is pyrolysis. Pyrolysis is the thermal degradation of material (plastic) in the absence of air.

Highways and roads demand enormous amount of material for its construction. The necessity for earth based material creates impacts of resource depletion, environmental degradation and energy consumption. Waste materials can replace some of the natural materials used in highway construction and the benefits of such alternative material include economic development opportunities and reduced environmental pollution. Also, the cost of haulage is the single largest variable in determining the cost of aggregate in road construction and substantial amount of cost will be saved if a partial replacement is devised from using pelletized plastic as aggregate.

The need to involve waste plastic in bituminous mixes cannot be over emphasized. Suggestions has been made that recycled polyethylene from grocery bags can be useful in asphaltic pavements resulting in a reduced permanent deformation in the form of rutting and reduced low-temperature cracking of the pavement surfacing [1, 2]. Hence recycled plastics composed predominantly of polypropylene and low density polyethylene can be incorporated into conventional asphalt road surfacing mixture achieving greater durability. Jew et al. [3] asserted that the use of polyethylene modified asphalt concrete mix displayed curious increases in both Marshall flow and Marshall stability values and conversely a decrease in flow value was reported in Hassani et al. [4].

Robert et al. [5], postulated that the improved properties of asphalt are as a result of the spread of long chain polymer molecules which creates an interconnecting matrix of the polymer through the bitumen. Also, Njiribeako [6] developed a procedure for managing solid plastic waste as a large scale commercial venture and suggested the adoption of pyrolysis as an alternative to incineration of plastic waste materials. In the same direction, Ojolo et al. [7] carried out the pyrolysis of shredded plastic wastes and observed that 0.025dm^3 of tar oil could be produced form 1kg of plastic waste leading to about 85.25% reduction in waste volume. Research in this area is entirely new and this paper attempts to further the investigation by utilizing available plastics in this part of the world to modify asphalt cement concrete for effective reduction in cost of road construction materials.

II. MATERIALS AND METHODS

The materials used for this study includes asphalt cement, coarse aggregate, inventive aggregate (pellet), fine aggregate, and filler (limestone dust). In blending the constituent materials (coarse, fine and filler), the sieve analysis result of Tables 1, 2 and 3 was used for the Rothfuch graphical method for the asphalt concrete while the combined aggregate gradation is shown in Table 4. The Rothfuch method of blending aggregate is one of the most useful graphical procedures in that it is reasonable quick and simple and can be applied to mixing any number of aggregate. The Rothfuch graphical result is shown in Figure 1, and base on the graph, the acceptable combination of the constituent materials were 48% of coarse aggregate, 43% of fine aggregate, and 9% of filler.

Table 1: Gradation Test on Coarse Aggregate

Sieve Size (mm)	Weight Retained	Cumulative Retained	Percent Retained	Percent Passing
12.5	-	-	-	100
9.5	200	200	40	60
4.75	247	447	89.4	10.6
2.36	51	498	99.6	0.4
1.18	-	-		
600 μ m	2	500		
300 μ m				
150 μ m				
75 μ m				

Table 2: Gradation Test on Fine Aggregate

Sieve Size (mm)	Weight Retained	Cumulative Retained	Percent Retained	Percent Passing
12.5	-	-	-	100
9.5	-	-	-	100
4.75	-	-	-	100
2.36	50	50	10	90
1.18	39	89	17.8	82.2
600 μ m	186	275	55	45
300 μ m	170	445	89	11
150 μ m	47	492	98.4	1.6
75 μ m	8	500	100	0

Table 3: Gradation Test on Filler

Sieve Size (mm)	Weight Retained	Cumulative Retained	Percent Retained	Percent Passing
12.5	-	-	-	-
9.5	-	-	-	-
4.75	-	-	-	-
2.36	-	-	-	-
1.18	-	-	-	-
600 μ m	-	-	-	-
300 μ m	2	2	2	98
150 μ m	8	10	10	90
75 μ m	90	100	100	0

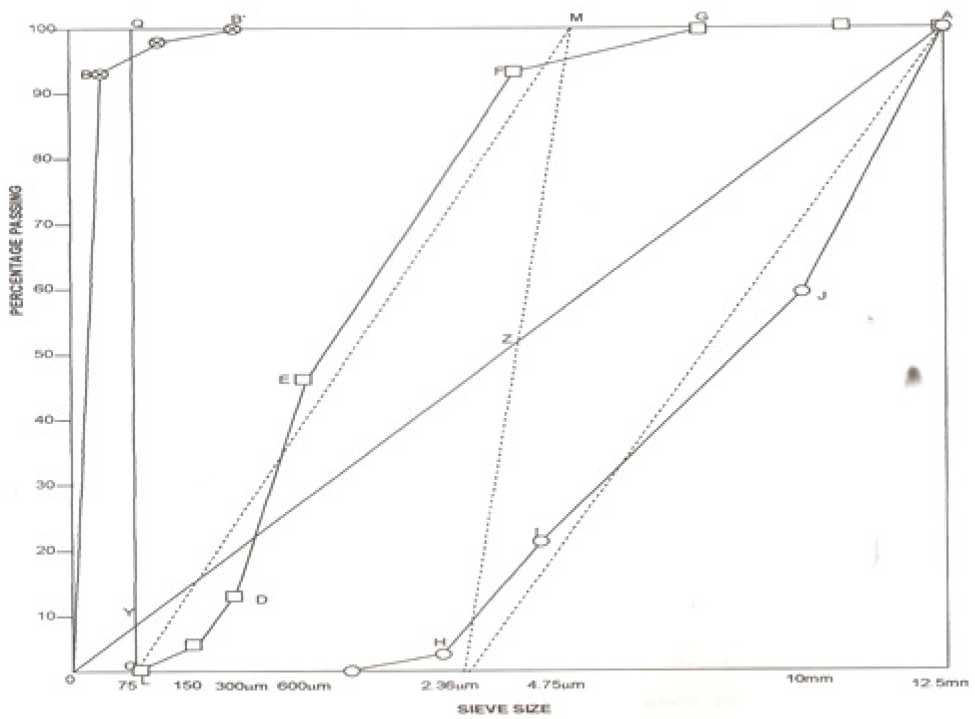

Figure 1: Rothfuch Graph

Table 4: Combine Aggregate Result

Sieve Size	Grading Limits	Required grading	Percent passing for Aggregate			A: 48% B: 43% C: 9%
			A: coarse	B: Fine	C: Filler	Combined Aggregate
12.5	100	100	100	100	100	100
9.5	80 -100	90	60	100	100	80.8
4.75	55 -75	65	11	100	100	57
2.36	35 – 50	43	1.0	90	100	48
1.18	-	-	-	82	100	-
600 μ m	18 – 29	24	-	45	100	28
300 μ m	13 – 23	18	-	11	100	14
150 μ m	8- 16	12	-	2	98	9
75 μ m	4- 16	7	-	-	90	8

b) Pyrolysis Chemical Process

The shredded waste plastic, extruded product and pellets gotten from the pyrolysis chemical process are shown in Figure 2, 3 and 4 respectively.

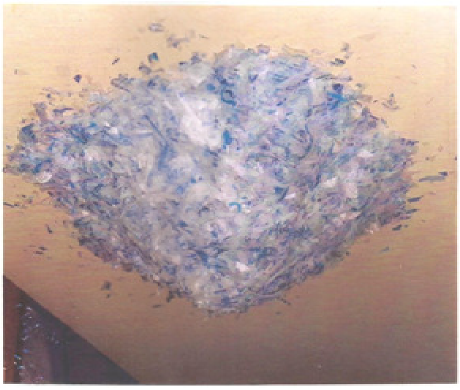

Figure 2: Shredded plastic bags **Figure 3:** Extruded product of plastic bags

Figure 4: Plastic pellet

III. MARSHALL MIX DESIGN METHOD

Marshall Stability test was carried out in order to determine the optimum bitumen content. The method adopts a trial mixture of asphalt cements contents over a portion of 0.5 percent interval. Three specimen is prepared, each requiring approximately 1200gms of mixture. Compaction achieving 50 blows was adopted, in an effort to maintain medium traffic category. Table 5 below shows Marshall Test data generated to obtain the optimum asphalt content with the associated graphs shown in figure 5a, 5b, 5c and 5d. The specific gravity of filler, fine and coarse aggregate were determined. Los Angeles abrasion test was conducted on the pellets to know if they are strong and tough enough to support loads imposed by traffic. Bulk density was determined for each specimen.

Table 5: Typical Marshall Test Data

Binder content (%)	Stability (kN)	Flow Units	Percentage of Air Voids in the Total Mixture	Percentage filled voids in the aggregate Component	Unit weight (Kg/ m^3)
4.0	6.15	3.39	6.48	58.59	2410
4.5	6.65	3.66	5.52	65.20	2430
5.0	7.88	3.81	4.47	72.10	2460
5.5	8.81	4.05	4.00	76.02	2500
6.0	8.20	4.70	3.33	80.58	2480
6.5	7.16	5.39	2.82	87.90	2450

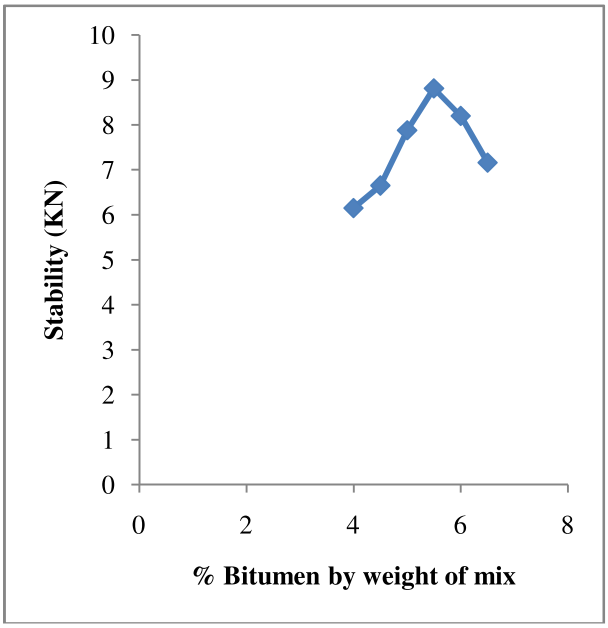

Fig. 5a: Stability (kN) vs percentage bitumen by weight of mix

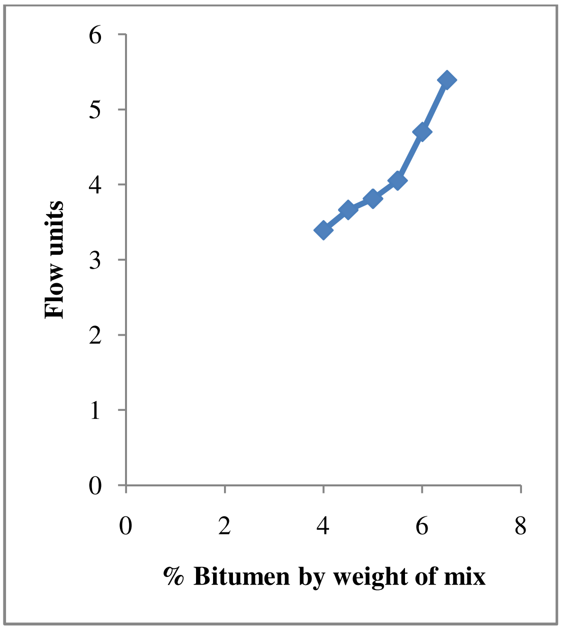

Fig. 5b: Flow units vs percentage bitumen by weight of mix

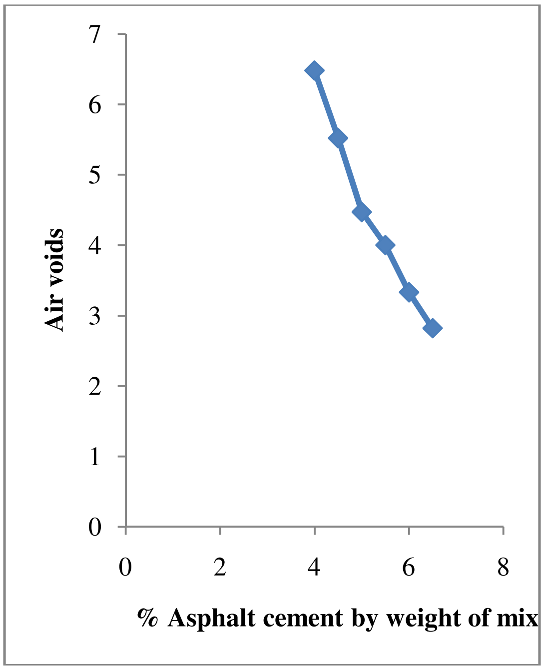

Fig. 5c: Air voids vs percentage bitumen by weight of mix

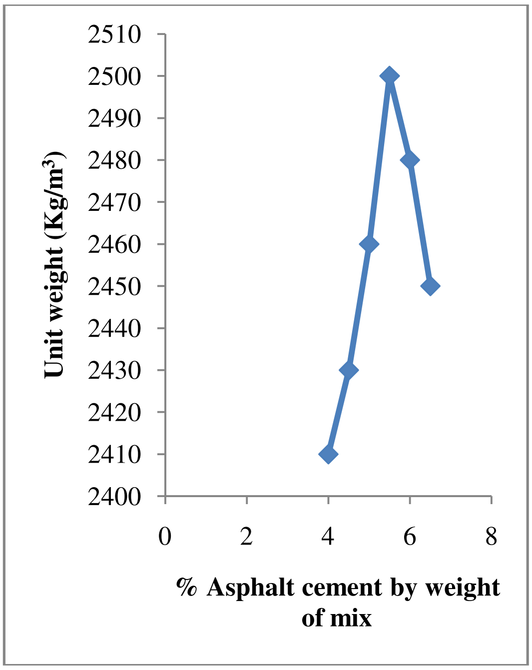

Fig. 5d: Unit weight vs percentage bitumen by weight of mix

From the analysis of the graphs, an average optimum bitumen content of 5.51% was adopted in this research.

IV. RESULTS AND DISCUSSIONS

The analysis and discussion of results presented in this section. The result of specific gravity, Los Angeles Abrasion loss and bulk density of the pellets are presented in Table 6, 7 and 8 respectively. Summary test result of stability, flow, percentage air voids, voids in mineral aggregates and unit weights of asphalt concrete made from specified percentages of plastic pellets are presented in Table 9. The analysis of results were also carried out using graphs as would be seen the different sections.

a) Specific Gravity Of Pellet

The result of specific gravity test carried out for plastic pellets is presented in Table 6 below. The specific gravity of the pellet ranges from 0.88 to 0.92, the average of 0.90 is lower than values for normal weight aggregate but meet requirements for light weight aggregates classification which is generally up to a maximum of 2.4 [8]. They are ideal for light to medium traffic roads.

Table 6: Specific Gravity of Plastic Pellet

Bottle /Test Number	1	2	3
Weight of bottle only (g) ----W_1	280	208	208
Weight of bottle and sample (g) -----W_2	315	320	330
Weight of bottle, sample and water (g) W_3	886	803	838
Weight of bottle water (g) --------------W_4	890	880	916
Gs = $\dfrac{W_2 - W_1}{(W_4 - W_1) - (W_3 - W_2)}$	0.90	0.88	0.92
Average Gs		0.90	

b) Los Angeles Abrasion Loss

The result of the Los Angeles Abrasion test carried out for plastic pellets is presented in Table 7 below.

Table 7: Los Angeles Abrasion Result of Pellet

Bottle /Test Number	1	2	3
Weight of specimen ----$W_{1\ (gm)}$	3000	3000	3000
Weight of specimen after test coarser than 1.70mm--------------------------------W_2(gm)	21565	2,616	2,577
Percentage Loss = $\frac{W_1 - W_2 X100}{W_1}$	14.50	12.80	14.10
Average percentage Loss		13.80	

The pellet has an abrasion loss of 13.8% and as reported in Robert et al. [5], abrasion loss less than 16% to a maximum of 50% are acceptable for road pavement material. A 13.8% abrasion loss for the pellet indicates that although they are lightweight aggregate, they have adequate resistance to wear. Therefore for strength and toughness criterion the pellets qualify as aggregate for road pavement construction.

c) Bulk Density of Pellet

The result of the test for bulk density carried out for plastic pellets is presented in Table 8.

Table 8: Bulk Density of Pellet

Parameter/test number	1	2	3	4
Volume (m^3)	0.0002198	0.0002179	0.0002203	0.0002193
Mass (g)	200	200	200	200
Density kg/m^3	910	918	908	912
Average	912kg/m^3			

The bulk density of most lightweight aggregate (clay, slate, slag, fly ash, etc.) vary from 480-1120kg/m^3 while value of 1440 -1760kg/m^3 are common for normal weight aggregate [9]. The pellets with a density of 912kg/m^3 falls within the limit of lightweight aggregate.

d) Stability of Asphaltic Concrete

The variation of stability with plastic pellet content is shown in Figure 6 while a summary of asphalt concrete mixis shown in Table 9. The value of the stability increases from 9.56KN at 0% plastic aggregate content to 14.81KN at 12% plastic aggregate content. This shows 36.06% increase in stability.

Table 9: Summary Result Sheet for Asphalt Concrete Mix Design

PERCENT PELLET									TRAFFIC CATEGORY	HEAVY (TYRE PRESSURE 1.4MN/M^2	MEDIUM (TYRE PRESSURE (0.75MN/M^2)
PARAMETER	0	2	4	6	8	10	12		PAVEMENT USE	HEAVY TRAFFICKED HIGHWAY	HIGHWAY WITH LOW TRAFFIC
									NO OF BLOWS AT EACH END OF SPECIMEN	75	50
Stability (kN)	9.56	12.10	12.43	13.46	13.99	14.30	14.81			650kg	200kg
Flow	6.00	5.43	5.04	4.88	4.04	3.85	3.42			16max	20max
Percent air void	4.08	3.45	3.17	2.74	1.61	0.487	0.269			3-3	3-5
V.M.A	75.64	78.40	79.59	81.70	88.33	96.14	97.82			75-82	75-85
UNIT WEIGHT Kg/m^3	2350	2331	2292	2268	2259	2250	2222				

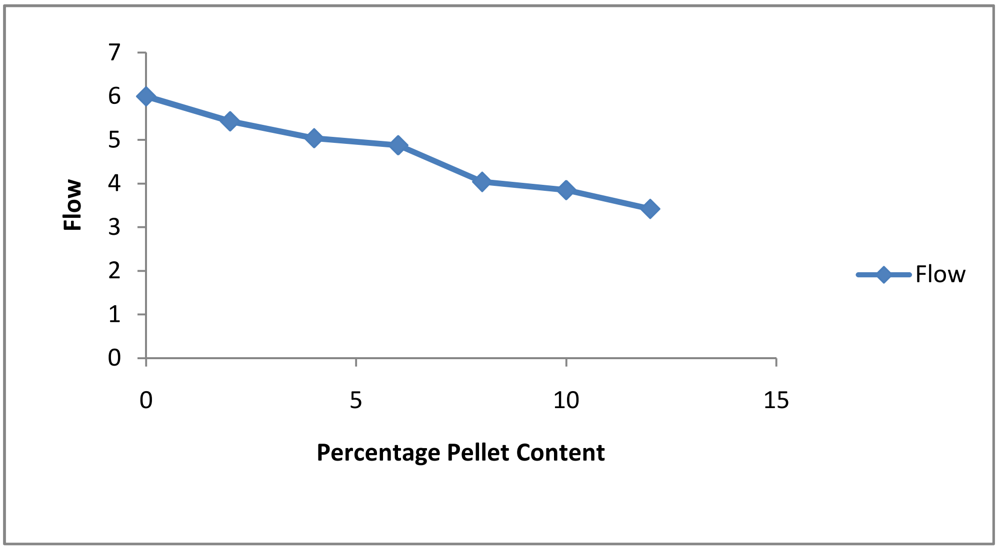

Fig. 6: Graph of Stability vs. Percentage Pellet Content

e) Asphaltic Concrete Flow

The variation of flow with percent plastic aggregate pellet is shown in figure 7. The value of flow decreases from 6.00mm at 0% plastic pellet content to 3.4mm at 12% plastic pellet content. This shows a reduction of about 43%. Within the limit acceptable by Marshall design criteria, plastic pallets contents of 2% to 4% showed a flow reduction of 9.5% to 16%.

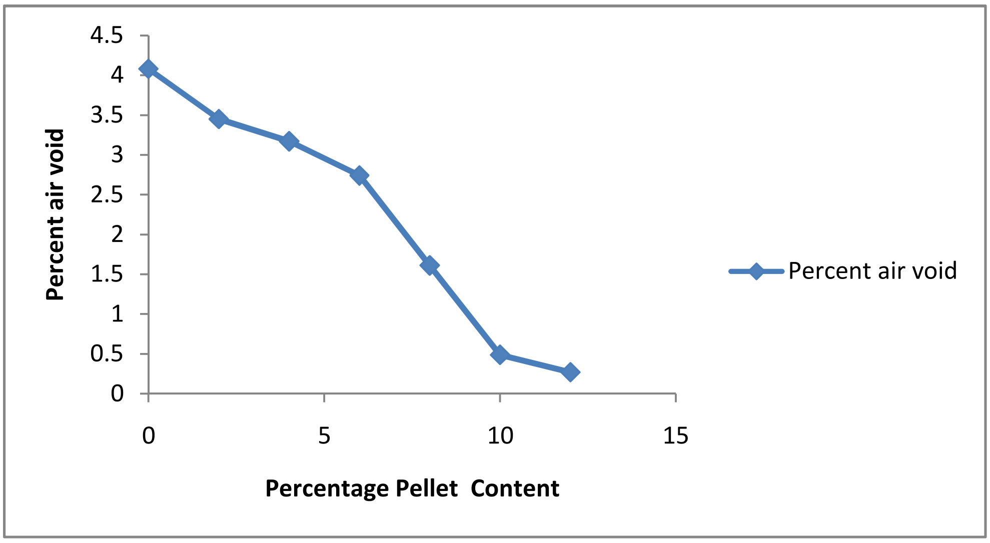

Figure 7: Flow vs Percent Pellet Content.

f) Percent Air Void

The relationship between air void against % pellet shows that air void reduces as the percent of pellet is increased as depicted in Figure 8 below.

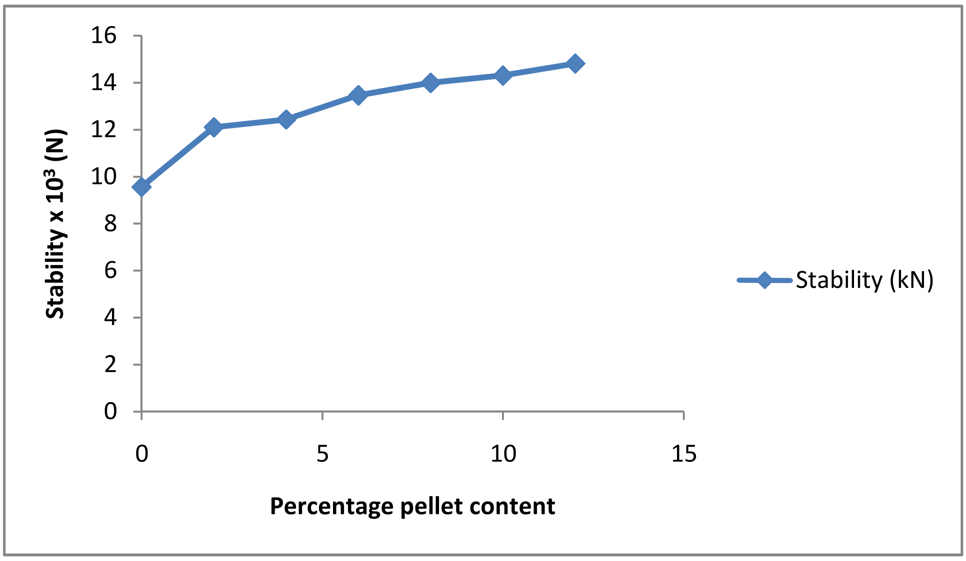

Figure 8: Percent air voids vs Percent Pellet Content.

h) Asphaltic Concrete Percent Voids in Aggregate Filled with Bitumen

The relationship between void filled with mineral aggregate against percent pellet as shown in figure 9 reveals that as the percent pellet increases, the value of void filled with mineral aggregate (V.M.A) also increases.

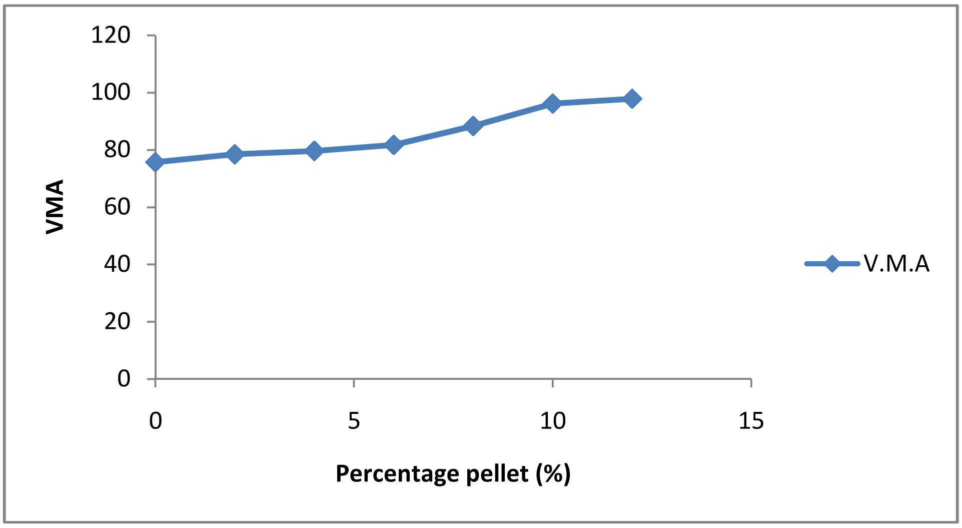

Figure 9: Percent of Filled Voids In The Aggregate Component vs Percent Pellet.

V. CONCLUSION

The aim of this research was to determine the suitability of asphalt cement concrete mix with the introduction of plastic pellets as partial replacement for aggregate. Severally laboratory tests were conducted to guarantee adequate stability of the produced asphalt concrete. The following conclusion can be drawn from the results obtained.

(i) The average specific gravity and density of 0.90 and 912kg/m^3 respectively is lower than values for normal weight aggregate but meets requirements for classification as light weight aggregate

(ii) A 13.8% abrasion loss for the pellet indicates that although they are lightweight aggregate, they have adequate resistance to wear.

(iii) Air void is tremendously reduced to approximately zero when the plastic pellet proportion exceeds 10 percent.

(iv) The value of the stability increases from 9.56KN at 0% plastic aggregate content to 14.81KN at 12% plastic aggregate content.

(v) Within the limit acceptable by Marshall design criteria, plastic pallets contents of 2% to 4% showed a flow reduction of 9.5% to 16%.

(vi) In this research pellet content in asphalt cement concrete satisfies some criteria in the Marshall requirement and fails in other requirements. Hence the use of plastic pellet as partial replacement for coarse aggregate is most efficient at 2 to 4 percent pellet content in asphalt concrete.

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